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LAC-171E-81-064

SUBJECT: SCATHA Data and Modeling Analysis
Contract No. F04701-80-C-0009
Model Validation/Test Evaluation Status Report
CDRL A009

TO: Maj. J. Roberts (SD/YLVS)
Air Force Space Division
P.O. Box 92960
Worldway Postal Center
Los Angeles, CA 90009

1.   Enclosed is the SCATHA Model Validation/Test Evaluation Status
Report, CDRL A009, in compliance with the subject contract.
Questions should be directed to Ed O'Donnell at SAI.

Sincerely yours,

SCIENCE APPLICATIONS, INC.

Alan B. Holman

ABH/bke

Enclosure

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SPACECRAFT CHARGING MODEL VALIDATION/TEST EVALUATION STATUS REPORT

CDRL A009

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SUBMITTED TO:

DEPARTMENT OF THE AIR FORCE
HQ SPACE DIVISION
LOS ANGELES AIR FORCE STATION
LOS ANGELES, CALIFORNIA

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SPACECRAFT CHARGING
MODEL VALIDATION/TEST EVALUATION STATUS REPORT
CDRL A009

1.0 INTRODUCTION

One of the primary objectives of the cooperative NASA/
Air Force Spacecraft Charging Investigation is to ensure
that validated analytical models and test techniques are
available for the assessment of spacecraft interactions with
the space environment. Historically, the modeling activity
has been divided into four regions:

- The undisturbed environment
- The plasma sheath surrounding the spacecraft
- The spacecraft surface
- The spacecraft interior

Models must be capable of predicting the degradation
(permanent damage or anomalous behavior) of spacecraft due
to the environment. Also, test techniques must be developed
for the purposes of providing input data for the models, or
for certifying that the spacecraft fulfills its design
requirements.

This report is an update to the Model Validation/Test
Evaluation Status Report (CDRL 006A2) submitted August 1979
by SAI. Since the previous report a number of significant
developments have occurred, and plans for additional tests
and analyses have been made.

In the past year, P78-2 data have been integrated into
an environmental Atlas. NASCAP predictions have been compared
with the P78-2 SSPM sample measurements. Two major electron
spraying experiments have been conducted on geometric spacecraft

7

models for which coupling predictions have been made. A quasi-static model of the SGEMP code SABER has been developed and exercised, and significant work has been reported on the emission of current during discharges. Also, P78-2 internal coupling data have been compared with predictions based upon ground test data and discharge models.

These developments, and others, will be described more fully in the following sections.

2.0 ANALYTICAL MODELS

In order to be able to predict the interaction of a spacecraft with the charged particle environment, analytical models must be employed. These models consist of an environmental model, a plasma sheath model which can predict spacecraft surface potentials, discharge models describing the electrical characteristics of the discharge, and coupling models to predict the electrical response of the spacecraft and the electromagnetic interference associated with discharges.

The status of analytical models is discussed below. Figure 1 presents a schedule of the model validation activities through October 1981.

2.1 ENVIRONMENTAL MODELS

Using data from P78-2, the Air Force Geophysics Laboratory (AFGL) has published a preliminary environmental Atlas. [1] This document is limited by the availability of data; both SC-5 and SC-9 data were available only for a total of 44 days. Unfortunately, the present version of the Atlas contains no data from charging events. However, a more complete version is in preparation, with a draft environmental Atlas expected to be complete by August 1981.
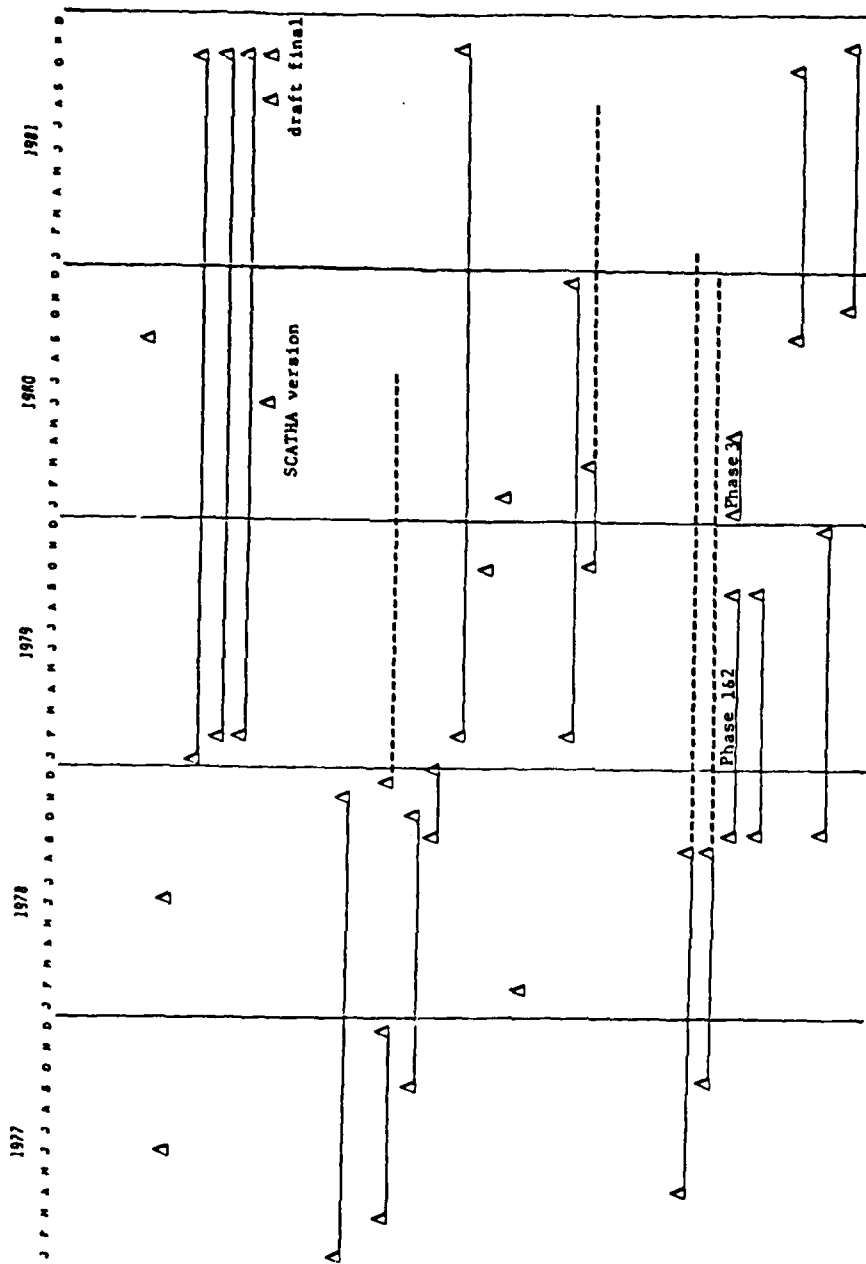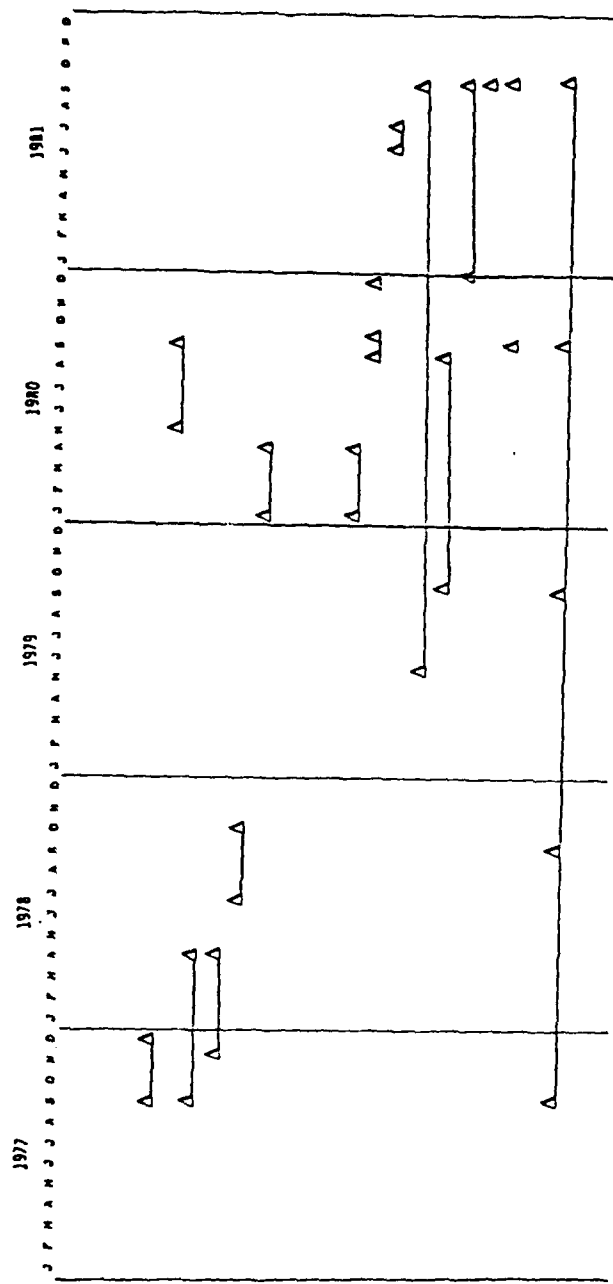
Figure 1. Model Validation Program Schedule

ENVIRONMENTAL MODEL

MAYA Preliminary Spec Aug 1976
NASA Provisional Spec Oct 1976
NASA Provisional Spec Update
SCATHA Data Requirements (AFGL)
SCATHA Operation
SCATHA Data Analysis (AFGL, Experimenters)
Daily Environmental Summaries
AFGL Atlas

CHARGING MODEL

NASCAP Development (S^3)
NASCAP Workshops
Material Sample Tests (NASA LeRC)
SCATHA Charging Analysis (AFGL/S^3)
NASCAP Extension
SCATHA Data Analysis (NASA LeRC, AFGL)
SCATHA Data Review (AFGL)
NASCAP - SSPH Comparisons (NASA LeRC)
Planar Charging Model (SAI)
Planar Model Development & Validation
  (Parker/IM)
SCATHA Charging Analysis (S^3)

DISCHARGE MODEL

AFOSR/SRI Experiments
NASA/IM Experiments
AFGL Experiments (IRT)
AFWL ECEMP Program
DNA Electron Spraying Tests (MRC)
University of Toronto Experiments
Electromagnetic Measurements (SRI)
Avalanche Discharge Model Development (SAI/BA)
Discharge Spec. for MIL-STD (SAI/BA)

3

COUPLING MODEL

SGEMP Code Conversion (IRT)
Quasistatic Model (IRT)
SCATSAT Coupling Analysis (IRT)
SCATSAT Discharge Tests (IRT)
SCATSAT Capacitive Drive Tests (IRT)
ABORC Calculations (Jaycor)
Electron Spraying Tests
Skynet Test (MRC)
CAN Test (IRT)
AFWL Spraying Tests (CSS/Jaycor)
SCATSAT Electron Test (IRT)
FLTSATCOM Experiment
SCATHA Data Analysis (SAI)
SCATHA Immunity Margins (TRW)
SCATSAT/SCATHA Data Comparisons (SAI/IRT)
Validated Coupling Model (SAI/IRT)
Test Specifications (IRT)

MIL STANDARD Development (SAI)

1977   1978   1979   1980   1981

Figure 1.   Model Validation Program Schedule (Cont'd)

4

2.2 SHEATH/CHARGING MODELS

Applications of the NASCAP code continued during the past year. Stevens, et al [2] compared NASCAP calculations of the P78-2 SSPM sample potentials to flight data and reported agreement to within 15%. This would appear to satisfy the requirements for validation of NASCAP. However, experiments reported by Treadaway, et al [3] appear to cast some doubt upon the validity of the SSPM measurements.

Schnuelle, et al [4] have performed detailed analyses of the charging of the P78-2 spacecraft in a variety of substorm conditions. They predict that the SCATHA booms are the most likely locations for discharges to occur. Also, calculations of the spacecraft potential for day 89 of 1979 (when the telemetry malfunction occurred) are presented, as well as a detailed study of gun operations.

In another paper, Stevens [5] extended NASCAP to model the effects of punchthrough and blowoff from discharges on spacecraft potential distributions. It is shown that large changes in the spacecraft potential will occur, subsequent to a discharge, with the result that adjacent dielectric surfaces can be expected to discharge. This coincides with observed "triggering" of discharges, once a given specimen has discharged.

Purvis [6] applied NASCAP to the study of spacecraft charging of sunlit surfaces. It was found that potential barriers formed by shaded dielectrics can inhibit photo-electron emission from lighted surfaces. Because of the slow charging rates, it was concluded that equilibrium conditions are not representative of true spacecraft charging response in a time-varying substorm.

The interaction of the plasma sheath with high voltage space power systems has been treated using NASCAP in two papers. Mandell, et al [7] compared the plasma power losses of a linear array to that of a modular array and concluded that the power loss differences were negligible. Stevens [8] used NASCAP to model the interaction of the space plasma with large, high voltage power systems. He concluded that the power losses were minimal (~1%) but that large electric field strengths could cause arcing in the dielectrics, which could cause difficulties in the proposed long lifetimes of the space power systems.

2.3 DISCHARGE MODELS

There has been a great deal of recent activity in the theoretical modeling of discharges, especially in the treatment of the blowoff charge. In addition to the theoretical work, a substantial amount of experimental data have become available.

When a charged dielectric surface exceeds the breakdown potential, an arc forms to a nearby conductor. It has been found that the arc is accompanied by an emission of some charge (usually 25% to 50% of the stored charge) from the dielectric surface. Data indicate that the duration of the charge emission (known as "blowoff") is the same as the duration of the arc. The exact nature of the blowoff charge and the manner in which it is released is not known.

Stettner and Marks [9] have investigated three models of the charge release: a uniform blowoff model, in which it is assumed that the charge appears uniformly above the surface; a moving region model in which the charge source is a ring propagating outward across the surface; and an edge model in which all charge is omitted at the edge. They conclude that, in the uniform emission and moving source models, space charge limiting will cause major deviations

from observed scaling laws (in which the blowoff charge is proportional to surface area) for sample sizes greater than 5 cm. Since this deviation has not been observed, they conclude that the source of charge must be at the edge of the sample.

A similar conclusion was reached by Katz, et al [10], who treated the dielectric as a space-charge limited cathode. They found that most of the emitted charge came from the edge of the sample.

It is generally accepted that a discharge, regardless of where it is initiated, propagates through conducting tracks formed just below the dielectric surface. Stettner and Dancz [11] solved for the time-dependent fields assuming the conducting track was a filament buried in a charged medium. Using this model, the late time current varied inversely proportional to time.

Inouye also considered the discharge propagation with the Brushfire model, which is documented in Reference 12. TRW's work concludes that G' (the ratio of blowoff current to arc current) may be as high as 58%.

Beers, et al [13] have performed calculations of the charging of Teflon and Kapton and the electromagnetic fields associated with discharges. The main conclusions regarding the electromagnetic field calculations are that space charge limiting can significantly affect the blowoff current, and that the presence of transverse fields will modify the functional behavior (e.g., inverse r, inverse r^2, etc.) of the fields.

Beers' calculations were performed to support the experimental measurements of Milligan, et al [14] at SRI, who measured electric and magnetic fields near the discharge source. Peak electric fields were on the order of 40 kV/m, varying inversely with r^3. It is important to realize that the fields are strongly dependent upon the blowoff charge motion, which is affected by the test geometry. Thus, the fields will be different in space than in the laboratory, and, indeed, will vary from location to location on the spacecraft.

Other discharge experimental programs of interest have been conducted by Balmain [15], Yadlowski [16], Mallon, et al [17], and Treadaway [3]. Balmain studied the dependence of the blowoff current upon incident electron flux for fluxes ranging from 0.8 to 100 nA/cm^2. Kapton showed a consistent variation in peak blowoff current amplitude and released charge (both increase as flux increases), whereas no such relationship was observed for Teflon or Mylar. The pulse duration showed no dependence on flux, which is consistent with present models.

Yadlowski observed a pronounced anisotropy in Teflon, and noted two significantly different types of discharges, depending upon whether the grounding edge was parallel or perpendicular to the preferred direction of discharge propagation. The breakdown potential for perpendicular orientation was 10 to 14 kilovolts less than for parallel orientation. Energetic electrons were observed in both orientations, but no ions were observed for the perpendicular orientation.

The Jaycor experiments [17, 3] were performed under
subcontract to Computer Sciences Corporation as part of the
AFWL ECEMP (electron caused electromagnetic pulse) program.
This program includes discharge characterization experiments
for low and high energy electron irradiation, analytic
modeling of coupling to spacecraft-like geometries, an
electron spraying experiment of a simple geometry (cannister),
and will include a system level electron spraying experiment
of the FLTSATCOM (FSC) Qual Model. Discussions of the
coupling and system test programs are described in later
sections of this report.

Mallon, et al [17] exposed a simulated FSC solar panel
to a combined high and low energy electron flux. Data are
presented for blowoff charge. They observed that the
presence of high energy electrons reduced the discharge
amplitude, isolating the panel from tank ground through a
high impedance reduced the discharge by a factor of 20 or
more, and that the presence of UV eliminated discharges
until the flux was increased.

Treadaway [3] performed a series of low flux experiments
on FSC materials. The conclusions were that high energy
electrons reduced or eliminated discharges from second
surface mirrors. Discharges on FSC cables were observed for
fluxes exceeding 200 pA/cm^2.

The Jaycor experiments also included exposure of the
SSPM samples similar to those flown on P78-2. It was
observed that the SSPM surface potential measurements were
not affected by the presence of high energy electrons, a
result which is inconsistent with previous results from the
ECEMP program. Jaycor suspects that the discrepancy is due
to the SSPM geometry and states: "We believe that the
surface potential as measured by the SSPM is not in all
cases a good indication of the sample surface potential.

The rate of change in surface potential as measured by the
SSPM in the center of a sample will be approximately 1/12
that of the rest of the sample surface."

2.4 COUPLING MODELS

The similarity between the discharge coupling problem
and the nuclear SGEMP response has led to the application of
computer codes developed for SGEMP to the discharge coupling
problem. There were some difficulties to be overcome,
primarily caused by the long discharge pulse duration
(compared to the SGEMP source) which causes excessive
computer time usage. This problem has been addressed by IRT
[18] by adding a quasi-static algorithm to the SABER code.
A similar approach has been used by Jaycor with the ABORC
code [19].

As part of the AFWL ECEMP program, Jaycor performed a
series of experiments in which simple geometric configurations
with dielectric surfaces were exposed to electron irradiation.
These experiments are described in References 20, 21, 22,
and 23.

Figure 2 illustrates the test configuration, and Figure
3 shows the test object geometries. The object in Figure 3a
is a cylindrical cannister with a dielectric surface on one
end. It is instrumented with surface current probes ($\dot{B}$)
along the sides, and connected to tank ground through a
variable resistance. In figure 3b, an object simulating an
antenna and mast has been added.

The Jaycor ABORC calculations indicate that in the
experimental configuration, charge emitted from the end
dielectric surface swarms around the body, returning to the
surface as late as several microseconds after the discharge
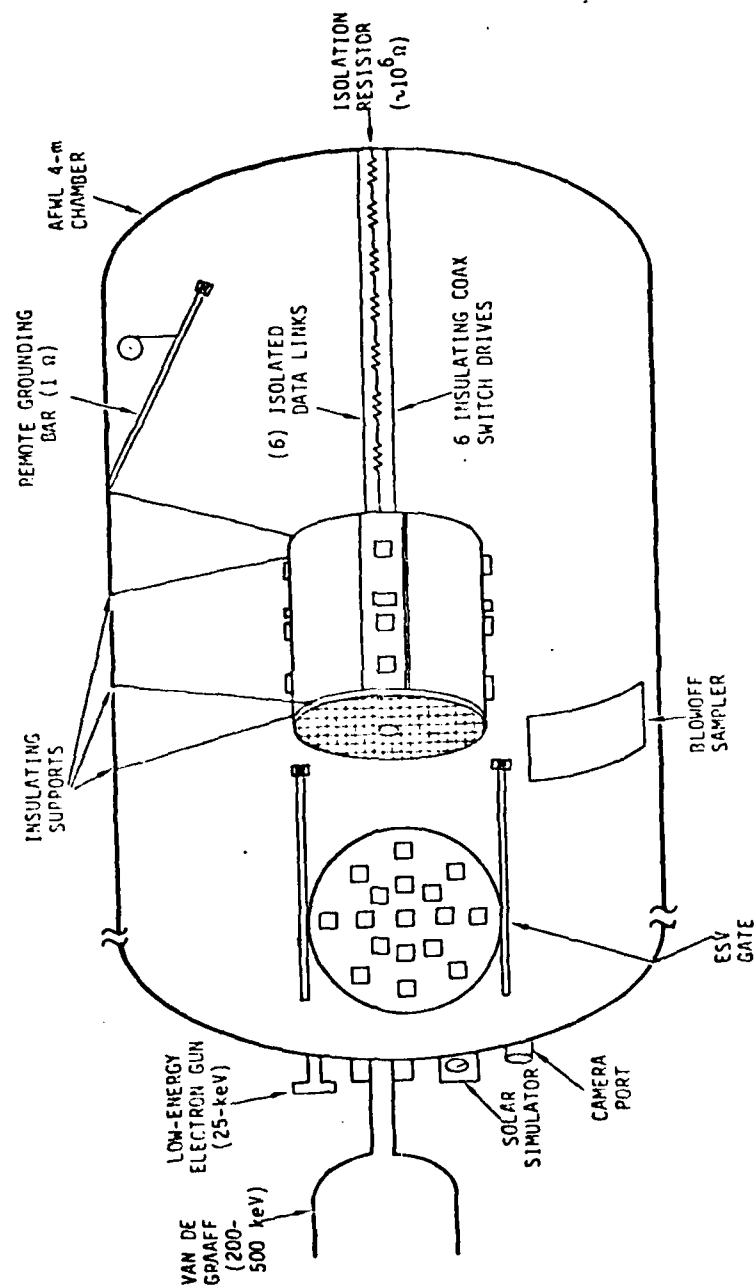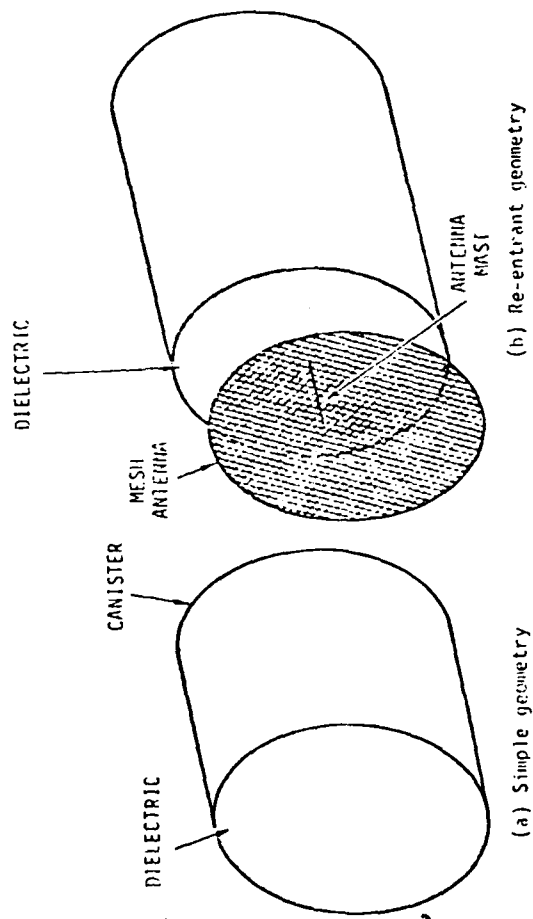begins. Jaycor has prepared a movie of the charge motion,

Figure 2. Phase III experimental configuration

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DIELECTRIC

ANTENNA MAST

(b) Re-entrant geometry

MESH ANTENNA

CANISTER

DIELECTRIC

(a) Simple geometry

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Figure 3. Test Objects

12

of which frames are exempted in Figure 4 (from Ref 19).
Excellent agreement between computed body response (rate of
change of current) and the measurements on the cannister are
shown in Figure 5. Figure 5 (from Ref 24) compares the
measured and predicted response. The agreement is highly
encouraging, inasmuch as this is far from a trivial calculation.
It is seen that the difference between experiment and theory
is no greater than the experimental variances.

The theory had difficulty with the simulated antenna
mast of Figure 3b. For this geometry, the predicted mast
current was 32 amps, and the measured response was 600 amps
[24]. The suggested reasons for the discrepancy are plasma
effects, energetic electron emission (could overcome space
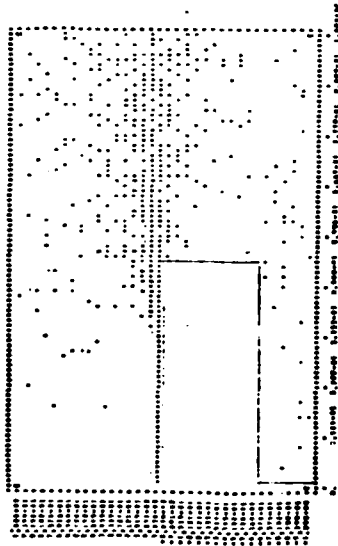charge barrier), and a concentrated emission source.

From the calculations, one can conclude that the
SGEMP-type codes can compute the coupled currents reasonably
accurately for simple geometries. Re-entrant geometries can
apparently have significant (order of magnitude) effects on
currents.
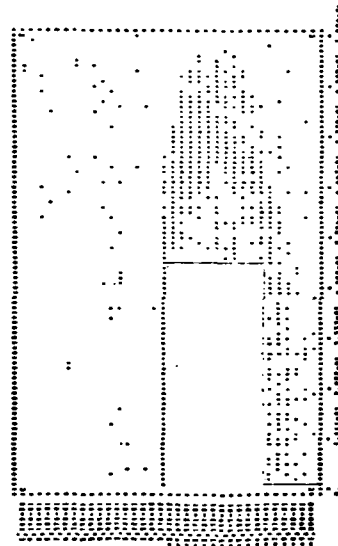
2.5 MATERIAL DAMAGE MODELS

There is no significant change in the status of material
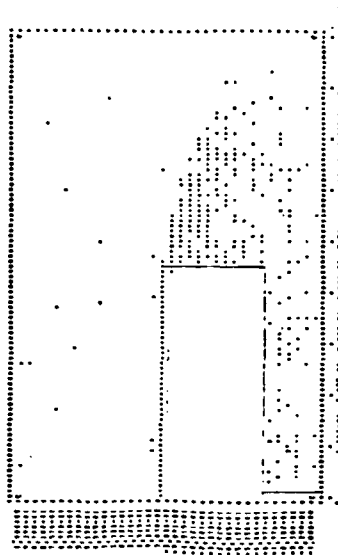damage models.

2.6 BURIED COMPONENTS MODEL

As part of the AFWL ECEMP program, Mallen, et al exposed
FSC cables to high energy electrons and measured the discharge
response [25]. It was found that shield currents ranged
from 4 to 10 amps, with center wire currents on the order of
40 to 100 mA. Sufficient energy was coupled to upset

(a) t = 200 nsec (b) t = 395 nsec (c) t = 2 μsec

Figure 4. Movie Plots of the Electron Cloud for Kapton Dielectric
with High-Impedance Grounding and Uniform Emission
(12.6 kV Initial Charge, 33% Blowoff)
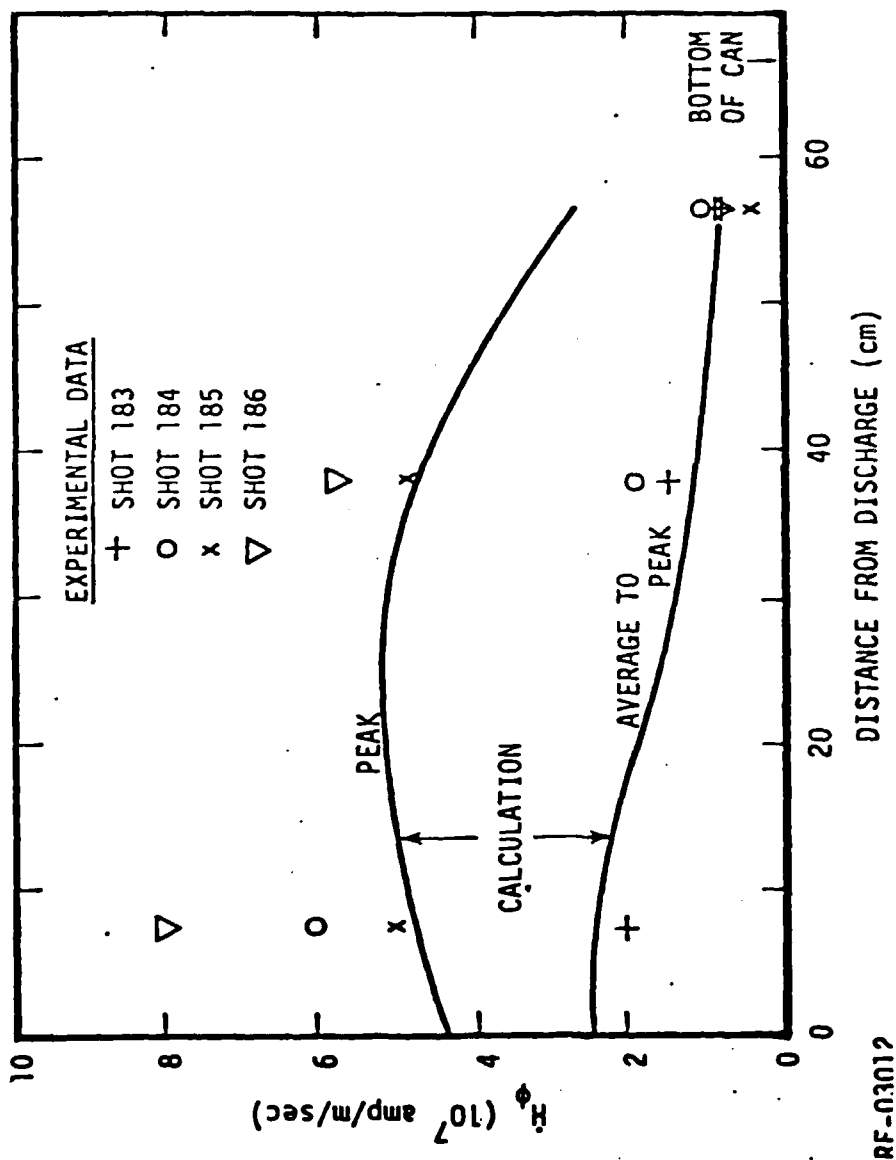
RE-02958

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Figure 5. Comparison of Analytical and Experimental Results

RF-03012

standard logic. For the GPS cables, the shield and wire currents were lower, as were the cujac and aljac wire currents.

3.0 SYSTEM TEST AND EVALUATION

One of the primary objectives of the Spacecraft Charging Technology Program is to develop system level test procedures to augment the spark test suggested by MIL-STD-1541B. This is presently conceived to be a capacitive drive technique, wherein a pulser is capacitively coupled to the spacecraft and discharged, exciting the system resonances. It is felt that this type of simulation best simulates the blowoff charge released during the discharge.

One of the problems expected with this technique is the difficulty in simulating the low frequency components of the long duration discharge pulse.

IRT has previously performed Capacitively Drive Injection (CDI) Tests on the SCATSAT model of the P78-2 spacecraft [26]. This test technique will be validated by a test program in progress at IRT, in which the SCATSAT model will be irradiated in the NASA Lewis Research Center plasma substorm simulator. By inducing discharges on the SCATSAT, measuring the coupling to internal wires, it will be possible to obtain data for a direct comparison with the CDI results. The SCATSAT discharge data will also be used for comparison with the P78-2 data (TPM, SC1-8B), which will serve as a measure of the quality of ground test simulations. Of equal importance, the SABER predictions of SCATSAT response will be evaluated on the basis of comparison with the SCATSAT test data. Figure 6 shows the interlinking elements of the SCATHA test and analysis verification programs.

Figure 6. SCATHA Model Evaluation and Validation Program Flow Chart

The SCATSAT Test Program consists of two phases. In the first phase, conducted in April 1980, IRT irradiated a cylindrical test object referred to as the CAN. The purposes of the CAN test were to check out the instrumentation system and to obtain coupling data on a simple object which could be more easily understood analytically than could SCATSAT. Although severely limited in test time, the CAN test was generally successful [27]. A detailed description of the CAN test is contained in References 28 and 29, and the overall IRT program plan is described in Reference 30.

The SCATSAT electron spraying tests are currently scheduled for September 1980 and November 1980 (two separate test periods).

A system test and evaluation program for an operational spacecraft is described in Reference 31. METEOSAT, a meteorological satellite, has experienced a number of anomalies which are attributed to spacecraft charging. Electron irradiation tests were conducted on the thermal control surfaces and the radiometer mirror to identify arc sources. Simulated arcing tests and electron spraying tests of the spacecraft were also performed, and design changes based upon those results were recommended.

Another major system level test is planned as part of the AFWL ECEMP program. The FLTSATCOM Qual Model will be subjected to electron irradiations in conjunction with an SGEMP experiment [32]. This test is presently planned for July 1981.

4.0 MIL STANDARD DEVELOPMENT

Under the present program plan for the Spacecraft Charging Technology Program, MIL-STD-1541 will be revised

by the end of FY82. From the point of view of the Model
Validation Task, this requires validated models of environ-
ment, charging, discharge, and coupling, as well as a set of
approved system test procedures by Oct 1981. It appears
that the environmental and charging models will be adequate
for this purpose.

In spite of a large amount of activity in the modeling
of discharges, it does not appear that any organization has
the responsibility of collecting all the data and formulating
it into a model suitable for MIL STD purposes. SAI and Beers
Associates have jointly proposed to provide this service for
Space Division.

The coupling model also appears to have some risk. Of
particular concern is the inability of ABORC to predict the
large current observed on the antenna mast in the Jaycor
experiment. At this phase of the program, no alternative to
the SGEMP code approach appears feasible, however, and it is
hoped that the SAI/BA discharge effort will be able to
resolve the issue. Understanding that experiment will be a
major task in the discharge modeling effort. (The feeling is
that the coupling code performed properly, but the source
term, i.e., the discharge, was not properly specified.)

The primary risk in the CDI test approach is the
inability to inject pulse lengths of the proper duration.
This is not expected to be a major problem, since the lower
frequencies will probably not couple well to spacecraft. At
worst, it may be necessary to overtest at the high frequencies
to cover the specified spectral content at low frequencies.

5.0 P78-2 DATA ANALYSIS

On day 87, 1979, the SC1-8B (pulse analyzer) recorded
an event on the harness wire sensor. This event coincided
with a TPM event and a sudden drop in the spacecraft
potential as determined by the SC9 spectrograph. Using the
discharge data provided by Balmain [33] and the capacitive
drive injection test data provided by IRT [26], O'Donnell
and Bates [34] predicted the response of the SC1-8B sensor
for that event. Figure 7 compares the predicted response
(the solid line) and the SC1-8B measurement (vertical bars).
Considering the crudeness of the data, the agreement is
highly satisfactory.

Figure 8 shows the SC1-8B recording of a discharge
event as detected by the external dipole. The solid line is
a computer fit to the data [35]. These data were recorded
with the pulse analyzer in Time State 6, which provides a
better resolution of the pulse than was the case in Figure
7.

Although the external dipole detects the electric field
strength external to the spacecraft, the waveform in Figure 8
should not be regarded as a measure of the discharge field.
The reason is that the waveform in Figure 8 appears to be
dominated by the satellite response. When IRT completes
their measurements on the SCATSAT external dipole, it will
be possible to interpret the data in Figure 8 more quantita-
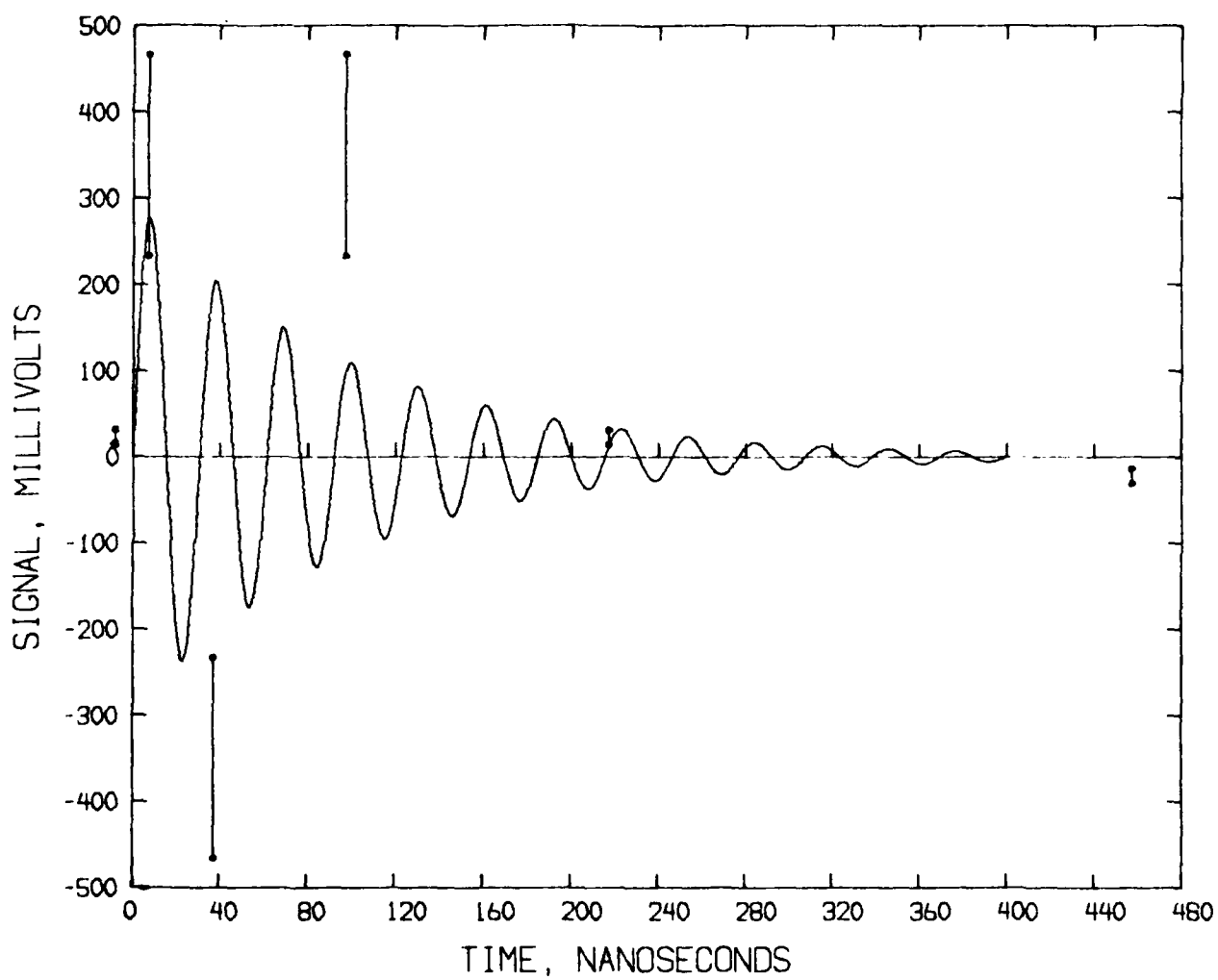tively.

Figure 7.   Predicted and Measured SC1-8B Response
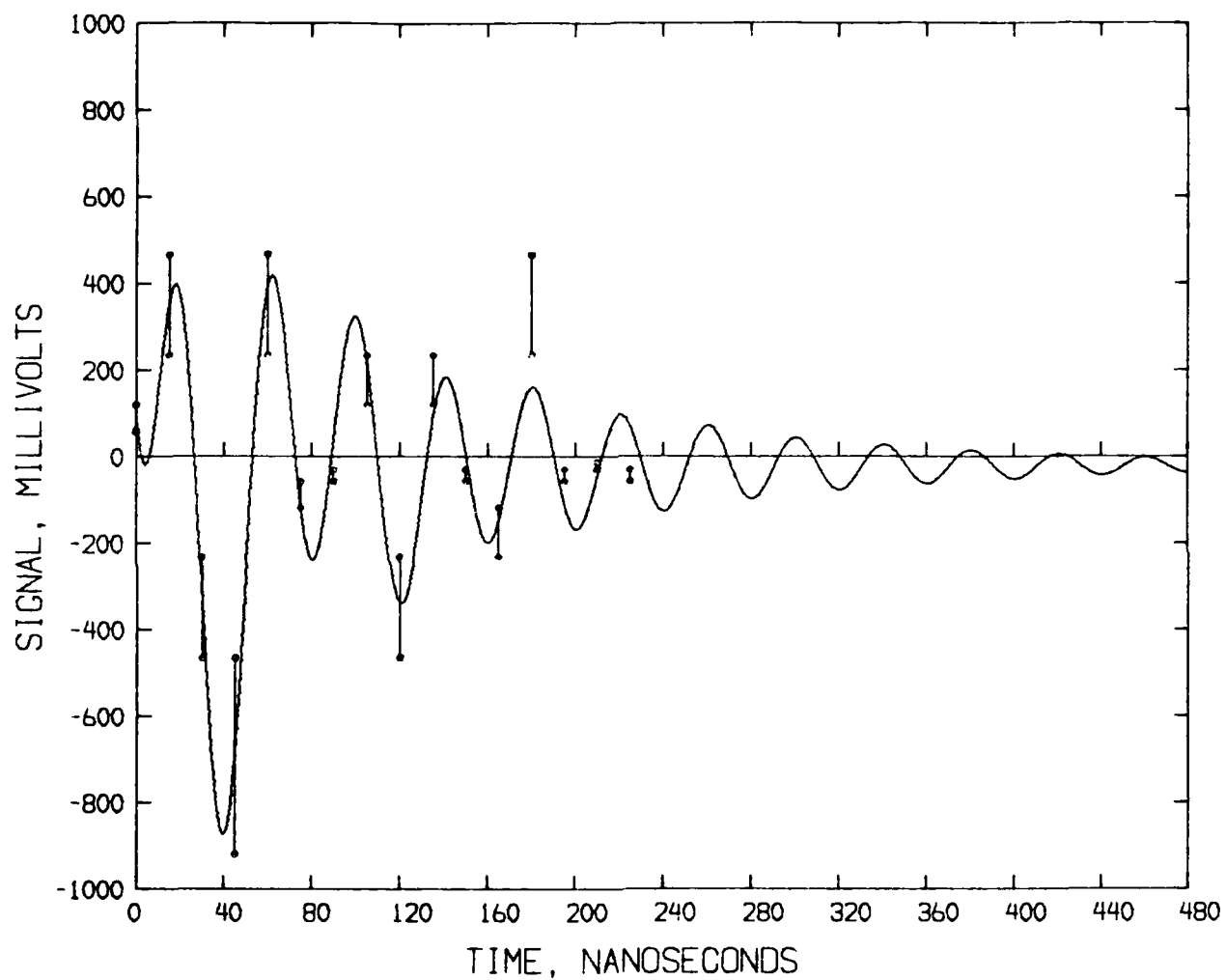   for the Event on Day 87, 1979

Figure 8. SC1-8B Measurement of External Dipole
Response

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